Chapter 8. Open Area Wind Erosion

This section was adapted from Section 13.2.5 of EPA's *Compilation of Air Pollutant Emission Factors (AP-42)*. Section 13.2.5 was last updated in January 1995.

8.1 Characterization of Source Emissions

Dust emissions may be generated by wind erosion of open areas of exposed soils or other aggregate materials within an industrial facility. These sources typically are characterized by nonhomogeneous surfaces impregnated with nonerodible elements (particles larger than approximately 1 centimeter [cm] in diameter). Field testing of coal piles and other exposed materials using a portable wind tunnel has shown that: (a) threshold wind speeds exceed 5 meters per second (m/s) (11 miles per hour [mph]) at 15 cm above the surface or 10 m/s (22 mph) at 7 m above the surface, and (b) particulate emission rates tend to decay rapidly (half-life of a few minutes) during an erosion event. In other words, these aggregate material surfaces are characterized by finite availability of erodible material (mass/area) referred to as the erosion potential. Any natural crusting of the surface binds the erodible material, thereby reducing the erosion potential. Loose soils or other aggregate materials consisting of sand-sized materials act as an unlimited reservoir of erodible material and can sustain emissions for periods of hours without substantial decreases in emission rates.

8.2 Emission Estimation: Primary Methodology[1-10]

If typical values for threshold wind speed at 15 cm are corrected to typical wind sensor height (7 to 10 m), the resulting values exceed the upper extremes of hourly mean wind speeds observed in most areas of the country. In other words, mean atmospheric wind speeds are not sufficient to sustain wind erosion from flat surfaces of the type tested. However, wind gusts may quickly deplete a substantial portion of the erosion potential. Because erosion potential has been found to increase rapidly with increasing wind speed, estimated emissions should be related to the gusts of highest magnitude. The routinely measured meteorological variable that best reflects the magnitude of wind gusts is the fastest mile. This quantity represents the wind speed corresponding to the whole mile of wind movement that has passed by the 1 mile contact anemometer in the least amount of time. Daily measurements of the fastest mile are presented in the monthly Local Climatological Data (LCD) summaries. The duration of the fastest mile, typically about 2 minutes (for a fastest mile of 30 mph), matches well with the half-life of the erosion process, which ranges between 1 and 4 minutes. It should be noted, however, that peak winds can significantly exceed the daily fastest mile.

The wind speed profile in the surface boundary layer is found to follow a logarithmic distribution as follows:

$$u(z) = \frac{u^*}{0.4} \ln \frac{z}{z_0} \quad (z > z_0) \tag{1}$$

where,

u = wind speed (cm/s)

u^* = friction velocity (cm/s)
z = height above test surface (cm)
z_0 = roughness height (cm)
0.4 = von Karman's constant (dimensionless)

The friction velocity (u^*) is a measure of wind shear stress on the erodible surface, as determined from the slope of the logarithmic velocity profile. The roughness height (z_0) is a measure of the roughness of the exposed surface as determined from the y-intercept of the velocity profile, i.e., the height at which the wind speed is zero. These parameters are illustrated in Figure 8-1 for a roughness height of 0.1 cm.

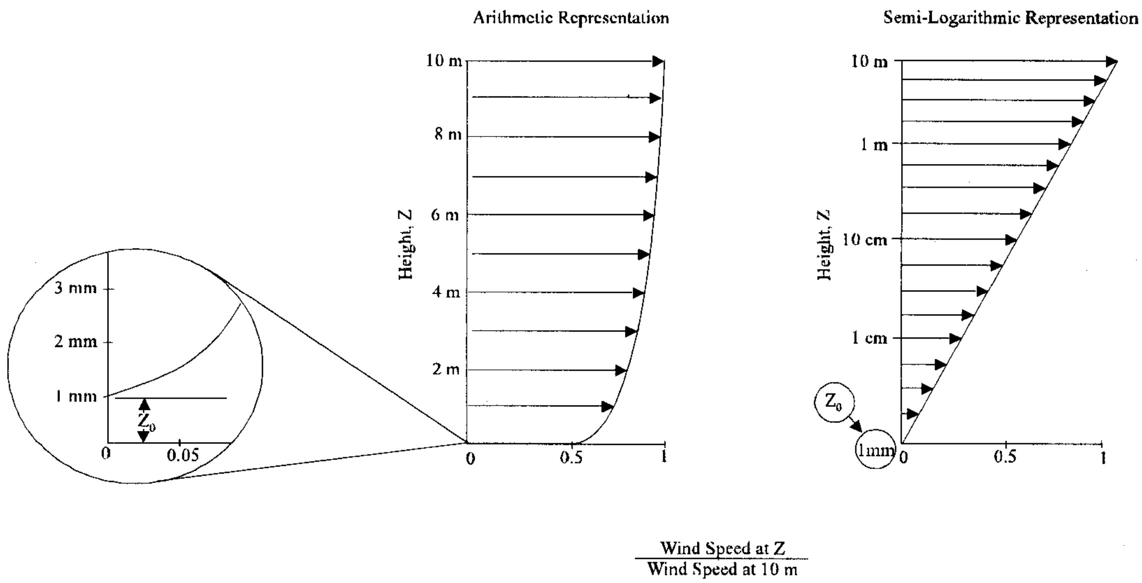

Figure 8-1. Illustration of Logarithmic Wind Velocity Profile

Emissions generated by wind erosion are also dependent on the frequency of disturbance of the erodible surface because each time that a surface is disturbed, its erosion potential is restored. A disturbance is defined as an action that results in the exposure of fresh surface material. On a storage pile, this would occur whenever aggregate material is either added to or removed from the old surface. A disturbance of an exposed area may also result from the turning of surface material to a depth exceeding the size of the largest pieces of material present.

The emission factor for wind-generated particulate emissions from mixtures of erodible and nonerodible surface material subject to disturbance may be expressed in units of grams per square meter (g/m^2) per year as follows:

$$\text{Emission factor} = k \sum_{i=1}^{N} P_i \qquad (2)$$

where,

k = particle size multiplier

N = number of disturbances per year
Pi = erosion potential corresponding to the observed (or probable) fastest mile of wind for the ith period between disturbances (g/m^2)

The particle size multiplier (k) for Equation 2 varies with aerodynamic particle size, as follows:

Aerodynamic Particle Size Multiplier (k) for Equation 2			
PM30	PM15	PM10	PM2.5
1.0	0.6	0.5	0.2

This distribution of particle size within the under 30 micrometer (µm) fraction is comparable to the distributions reported for other fugitive dust sources where wind speed is a factor. This is illustrated, for example, in the distributions for batch and continuous drop operations encompassing a number of test aggregate materials (see Chapter 4).

In calculating emission factors, each area of an erodible surface that is subject to a different frequency of disturbance should be treated separately. For a surface disturbed daily, N = 365 per year, and for a surface disturbance once every 6 months, N = 2 per year. The erosion potential function for a dry, exposed surface is given as:

$$P = 58 (u^* - u_t^*)^2 + 25 (u^* - u_t^*) \qquad (3)$$

$$P = 0 \text{ for } u^* \le u_t^*$$

where,

u^* = friction velocity (m/s)
u_t = threshold friction velocity (m/s)

Because of the nonlinear form of the erosion potential function, each erosion event must be treated separately.

Equations 2 and 3 apply only to dry, exposed materials with limited erosion potential. The resulting calculation is valid only for a time period as long or longer than the period between disturbances. Calculated emissions represent intermittent events and should not be input directly into dispersion models that assume steady-state emission rates. For uncrusted surfaces, the threshold friction velocity is best estimated from the dry aggregate structure of the soil. A simple hand sieving test of surface soil can be used to determine the mode of the surface aggregate size distribution by inspection of relative sieve catch amounts, following the procedure described below.

FIELD PROCEDURE FOR DETERMINING THRESHOLD FRICTION VELOCITY
(from a 1952 laboratory procedure published by W. S. Chepil[5])

Step 1. Prepare a nest of sieves with the following openings: 4 mm, 2 mm, 1 mm, 0.5 mm, and 0.25 mm. Place a collector pan below the bottom (0.25 mm) sieve.

Step 2. Collect a sample representing the surface layer of loose particles (approximately 1 cm in depth, for an encrusted surface), removing any rocks larger than about 1 cm in average physical diameter. The area to be sampled should be not less than 30 cm by 30 cm.

Step 3. Pour the sample into the top sieve (4-mm opening), and place a lid on the top.

Step 4. Move the covered sieve/pan unit by hand, using a broad circular arm motion in the horizontal plane. Complete 20 circular movements at a speed just necessary to achieve some relative horizontal motion between the sieve and the particles.

Step 5. Inspect the relative quantities of catch within each sieve, and determine where the mode in the aggregate size distribution lies, i.e., between the opening size of the sieve with the largest catch and the opening size of the next largest sieve.

Step 6. Determine the threshold friction velocity from Table 8-1.

The results of the sieving can be interpreted using Table 8-1. Alternatively, the threshold friction velocity for erosion can be determined from the mode of the aggregate size distribution using the graphical relationship described by Gillette.[5-6] If the surface material contains nonerodible elements that are too large to include in the sieving (i.e., greater than about 1 cm in diameter), the effect of the elements must be taken into account by increasing the threshold friction velocity.[10]

Table 8-1 Field Procedure for Determination of Threshold Friction Velocity (Metric Units)

Tyler Sieve No.	Opening (mm)	Midpoint (mm)	u_t* (cm/s)
5	4		
9	2	3	100
16	1	1.5	76
32	0.5	0.75	58
60	0.25	0.375	43

Threshold friction velocities for several surface types have been determined by field measurements with a portable wind tunnel. These values are presented in Table 8-2.

Table 8-2 Threshold Friction Velocities (Metric Units)

Material	Threshold friction velocity (m/s)	Roughness height (cm)	Threshold wind velocity at 10 m (m/s)	
			z_o = Actual	z_o = 0.5 cm
Overburden[a]	1.02	0.3	21	19
Scoria (roadbed material)[a]	1.33	0.3	27	25
Ground coal (surrounding coal pile)[a]	0.55	0.01	16	10
Uncrusted coal pile[a]	1.12	0.3	23	21
Scraper tracks on coal pile[a,b]	0.62	0.06	15	12
Fine coal dust on concrete pad[c]	0.54	0.2	11	10

[a] Western surface coal mine. Reference 2.
[b] Lightly crusted.
[c] Eastern power plant. Reference 3.

The fastest mile of wind for the periods between disturbances may be obtained from the monthly local climatological data (LCD) summaries for the nearest reporting weather station that is representative of the site in question.[7] These summaries report actual fastest mile values for each day of a given month. Because the erosion potential is a highly nonlinear function of the fastest mile, mean values of the fastest mile are inappropriate. The anemometer heights of reporting weather stations are found in Reference 8, and should be corrected to a 10-m reference height using Equation 1. To convert the fastest mile of wind (u^+) from a reference anemometer height of 10 m to the equivalent friction velocity (u^*), the logarithmic wind speed profile may be used to yield the following equation:

$$u^* = 0.053\, u_{10}^{+} \qquad (4)$$

where,

u^* = friction velocity (m/s)
u_{10}^{+} = fastest mile of reference anemometer for period between disturbances (m/s)

This assumes a typical roughness height of 0.5 cm for open terrain. Equation 4 is restricted to large relatively flat exposed areas with little penetration into the surface wind layer.

8.3 Emission Estimation: Alternate Methodology

8.3.1 Wind Blown Dust from Open Areas

MacDougall (2002)[11] developed a method for estimating fugitive dust emissions from wind erosion of vacant lan. This method, which relies heavily on emission factors developed for different vacant land parcels using wind tunnels, has been approved by EPA Region IX for Clark County, Nevada’s PM10 SIP. The availability of wind tunnel results for the types of vacant land being assessed must be considered when deciding to use this method for other applications. It should be pointed out that in 2003 Environ (under contract to the Western Governors’ Association) abandoned this approach due to the paucity of sufficient wind tunnel data for many different vacant land parcels in the western U.S. (Mansell, et. al., 2004).[12] Also, the WRAP's fugitive dust expert panel had major reservations regarding the MacDougall method (Countess Environmental, 2002).[13] Panel members were skeptical about using the proposed methodology since wind tunnels have shortcomings and do not represent actual conditions in nature. The panel concluded that determining emission factors in the manner proposed will result in significant underestimation of windblown dust for those cases where saltation plays a role.

The six steps described in the MacDougall method are summarized below.

<u>Step 1: Categorizing Vacant Land.</u> Vacant land within the study area must be categorized based upon the potential of the parcels to emit fugitive dust during wind events. Many wind tunnel studies have been conducted in the western United States, and the vacant land descriptions of the wind tunnel test areas should be used to categorize the vacant land within the study area. When categorizing vacant land, it is especially important whether the land has vegetation, rocks or other sheltering elements, whether the soil crust is intact or disturbed, and whether there are periodic activities on the vacant land such as vehicles or plowing that will change the land from fairly stable to unstable. Not every parcel of vacant land will necessarily fit into a category that has been wind tunnel tested. For parcels without a specific vacant land type wind tunnel test, assumptions will need to be made of the best representative land type and uncertainties noted.

<u>Step 2: Identify Wind Tunnel Emission Factors.</u> Based upon the vacant land categorization, wind tunnel results should be reviewed and applied appropriately to each category of vacant land. Wind tunnel results should be reviewed to determine if "spikes" from the initial portion of the test are presented separately or averaged into an hourly factor. Whenever possible, spikes should not be included in an hourly factor. The spike values should be included only at the beginning of each wind event.

<u>Step 3: Develop Meteorological Data Set.</u> For the area to be studied, hourly average wind speeds, rainfall, and if available peak wind gust data should be gathered. If a study area is particularly large, several different meteorological data sets may need to be gathered, and each land parcel matched with the meteorological data that impacts that parcel.

<u>Step 4: Determine Land Type Reservoirs, Threshold Wind Velocities, Wind Events, and Rainfall Events.</u> Based upon the wind tunnel results for each vacant land type, the wind speed when emissions were first measured for the vacant land type, should be set as the threshold wind speed. Most vacant land does not have an endless reservoir of fugitive dust; however, land that has a high degree of disturbance will continue to emit throughout a wind event. Therefore, for each vacant land type, the wind tunnel results should be reviewed and a determination made on the length of time the parcel will emit for a give wind event. It is recommended that an assumption be made that parcels with sheltering elements, vegetated parcels, or parcels with a soil crust will only emit during the first hour of a wind event. Parcels with a relatively high silt component or with frequent

disturbance will probably continue to emit throughout a wind event. Because most threshold wind speeds are relatively high (i.e., sustained hourly winds of 25 to 30 mph), a wind event may be defined as any time period when winds reach the threshold wind velocities separated by at least 24 hours before a new wind event is defined. Depending on the soils in an area, rain may have a large impact on wind erosion. Days with rain should not be included in the inventory.

Step 5: Develop Emission Inventory Specific Emission Factors. Using the reservoir determination, threshold wind speeds, wind event determination and rainfall factors, determine hours when wind conditions produced emissions from each vacant land parcel for the time period of the emission inventory. The number of hours with wind speeds in each wind speed category should be totaled. The number of hours can then be multiplied by the wind tunnel emission factor and a total emission factor for the time period of the inventory can be calculated. The emission factor equations for vacant land with and without sustained emissions are given as follows:

(a) With sustained emissions: $EF_1 = (\sum (H\ P))$

where, EF_1 = PM10 emission factor (lb/acre)
H = hours when wind conditions result in emissions
P = emission factor for a given vacant land category (lb/hour-acre)

(b) Without sustained emissions: $EF_1 = (\sum (W\ P))$

where, EF_1 = PM10 emission factor (lb/acre)
W = number of wind events when wind conditions result in emissions
P = emission factor for a given vacant land category (lb/acre)

The emission factor equation for spike emissions is given as:

$$EF_2 = (\sum (E\ S))$$

where, EF_2 = spike PM10 emission factor (lb/acre)
E = number of events producing spike emissions
S = spike mass for a given vacant land category (lb/acre)

Emission factors will vary from time period to time period and from vacant land type to vacant land type. Generally speaking, disturbed lands will have unlimited reservoirs and lower threshold wind velocities leading to much higher emissions than stable or sheltered parcels with one hour reservoirs. An emission factor should be developed for each vacant land category in the inventory.

Step 6: Apply Emission Inventory Specific Emission Factors to Vacant Land Categories. Once emission inventory emission factors have been developed, the number of acres in each category should be multiplied by the factor and the emissions totaled. It may be useful to develop certain factors over shorter time periods and then total the emissions over a longer time period. For example, one may want to develop winter factors and summer factors and then total them together for the annual inventory. For large areas, where vacant land categories will change over the duration of an inventory or different meteorological data sets will apply, it is advisable to subdivide the inventory by time period or area, and then total the inventory at the end. Annual emissions for each vacant land category are calculated as follows:

$$E = A\,(EF_1 + EF_2)$$

where, E = annual emissions for a given vacant land category
A = vacant land category acreage
EF_1 = annual emission factor for a given vacant land category
EF_2 = spike emission factor for a given vacant land category

Several alternative emission estimation methods for open area wind erosion have been developed that are still in the developmental stage and have not yet been approved by federal or state agencies. These methods are discussed in Appendix B. Because these methods have not been peer-reviewed, the reader is cautioned in the use of the emission factors included in these methods.

8.4 Demonstrated Control Techniques

Control measures for open area wind erosion are designed to stabilize the exposed surface (e.g., by armoring it with a less erodible cover material) or to shield it from the ambient wind. Table 8-3 presents a summary of control measures and reported control efficiencies for open area wind erosion.

Table 8-3. Control Efficiencies for Control Measures for Open Area Wind Erosion

Control measure	Source Component	PM10 Control Efficiency	References/comments
Apply dust suppressants to stabilize disturbed area after cessation of disturbance	Disturbed areas	84%	CARB, April 2002.
Apply gravel to stabilize disturbed open areas	Disturbed areas	84%	CARB, April 2002. Estimated to be as effective as chemical dust suppressants.

8.5 Regulatory Formats

Fugitive dust control options have been embedded in many regulations for state and local agencies in the WRAP region. Regulatory formats specify the threshold source size that triggers the need for control application. Example regulatory formats for several local air quality agencies in the WRAP region are presented in Table 8-4. The website addresses for obtaining information on fugitive dust regulations for local air quality districts within California, for Clark County, NV, and for Maricopa County, AZ, are as follows:

- Districts within California: www.arb.ca.gov/drdb/drdb.htm
- Clark County, NV: www.co.clark.nv.us/air_quality/regs.htm
- Maricopa County, AZ: www.maricopa.gov/envsvc/air/ruledesc.asp

8.6 Compliance Tools

Compliance tools assure that the regulatory requirements, including application of dust controls, are being followed. Three major categories of compliance tools are discussed below.

Record keeping: A compliance plan is typically specified in local air quality rules and mandates record keeping of source operation and compliance activities by the source owner/operator. The plan includes a description of how a source proposes to comply with all applicable requirements, log sheets for daily dust control, and schedules for compliance activities and submittal of progress reports to the air quality agency. The purpose of a compliance plan is to provide a consistent reasonable process for documenting air quality violations, notifying alleged violators, and initiating enforcement action to ensure that violations are addressed in a timely and appropriate manner.

Site inspection: This activity includes (1) review of compliance records, (2) proximate inspections (sampling and analysis of source material), and (3) general observations. An inspector can use photography to document compliance with an air quality regulation.

On-site monitoring: EPA has stated that "An enforceable regulation must also contain test procedures in order to determine whether sources are in compliance." Monitoring can include observation of visible plume opacity, surface testing for crust strength and moisture content, and other means for assuring that specified controls are in place.

Table 8-4. Example Regulatory Formats for Open Area Wind Erosion

CAPCOA				Clark County, NV				Maricopa County, AZ			
Control Measure	Goal	Threshold	Agency	Control measure	Goal	Threshold	Agency	Control measure	Goal	Threshold	Agency
Requires ceasing all active ops and applying water 15 minutes prior to moving soil. Requires for unpaved roads applying chemical stabilizers prior to wind event, applying water twice per hour during active operations, and stopping all vehicular traffic			SCAQMD Rule 403 12/11/1998	Use of one of following for dust control on all disturbed soil to maintain in damp condition: soil crusted over by watering or other, or graveling or treated with dust suppressant	Prevent visible fugitive dust from exceeding 20% opacity, and prevent dust plume from extending more than 100 yd		Clark County Sect. 94 Air Quality Reg. 06/22/2000	Watering, fencing, paving, graveling, dust suppressant, vegetative cover, restrict vehicular access	Maintain soil moisture content min 12%; or 70% min of optimum soil moisture content; reduce windblown emissions	Constr sites; fences 3ft-5ft, adjacent to roadways/urban areas;	Maricopa County Rule 310 04/07/2004
Requires application of water or chemical stabilizers prior to wind event 3 times a day (possible increase to 4 times a day if evidence of wind driven dust), or establish a vegetative cover within 21 days after active operations have ceased to maintain a stabilized surface for 6 months		For operations that remain inactive for not more than 4 consecutive days	SCAQMD Rule 403 12/11/1998	Particulate emissions must immediately cease		In the event that wind conditions occur that cause fugitive dust emissions to exceed 20% opacity in spite of the use of Best Available Control Measures (BACM)	Clark County Sect. 94 Air Quality Reg. 06/22/2000	Cease ops (wind spd >/=25mph); applying dust suppressant 2x hr; watering and fencing (as above); for after work hours: gravel, water 3x day (possibly 4)	Reduce amt of windblown dust leaving site; maintain soil moisture content 12% (as above)	Windspd must be >/=25mph for 60 min avg; (see above); fencing must be 3ft-5ft with </=50% porosity; watering for after work, holidays, wkds increase to 4x day during wind event	Maricopa County Rule 310 04/07/2004

The following table summarizes the compliance tools that are applicable to open area wind erosion.

Table 8-5. Compliance Tools for Open Area Wind Erosion[14]

Record keeping	Site inspection/monitoring
Soil stabilization methods; application frequencies, rates, and times for dust suppressants; establishment/ maintenance of wind breaks.	Crust strength determination (e.g., drop ball test); observation of operation of dust suppression systems; inspection of heights and porosities of windbreaks.

8.7 Sample Cost-Effectiveness Calculation

This section is intended to demonstrate how to select a cost-effective control measure for fugitive dust originating from open area wind erosion. A sample cost-effectiveness calculation is presented below for a specific control measure (apply gravel) to illustrate the procedure. The sample calculation includes the entire series of steps for estimating uncontrolled emissions (with correction parameters and source extent), controlled emissions, emission reductions, control costs, and control cost-effectiveness values for PM10 and PM2.5. In selecting the most advantageous control measure for construction and demolition, the same procedure is used to evaluate each candidate control measure (utilizing the control measure specific control efficiency and cost data), and the control measure with the most favorable cost-effectiveness and feasibility characteristics is identified.

Sample Calculation For Open Area Wind Erosion (Dirt Parking Lot)

Step 1. Determine source activity and control application parameters.

Dirt parking lot: size	100 m x 100 m
Disturbance frequency per day	1
Duration of exposure (months)	12
Roughness height (cm)	0.5
Threshold peak wind speed at height of 10 m (m/s)	10
Threshold peak wind speed at height of 10 m (mph)	22

Control Measure	Apply gravel
Control application/frequency	Once per year
Economic Life of Control System (yr)	5
Control Efficiency	Based on higher threshold friction velocity
Reference	Sierra Research, 2003[15]

The field size is an assumed value, for illustration purposes. Applying gravel has been chosen as the applied control measure. The control efficiency is calculated from the AP-42 emission factor equation (see Step 4).

Step 2. Calculate Emission Factor. The PM2.5 and PM10 emission factors are obtained from AP-42.

k—PM2.5 (dimensionless)	0.2
k—PM10 (dimensionless)	0.5
P—erosion potential (g/m^2)	$P = 58 (u^*-u^*_t)^2 + 25 (u^*-u^*_t)$
Threshold friction velocity u^*_t (m/s) = $0.053\ u^+_{10}$	0.53
A—source area (m^2)	10,000

Step 3. Calculate Uncontrolled PM Emissions. The emission factors (given in Step 2) are applied to each day for which the peak wind exceeds the threshold velocity for wind erosion. The following monthly climatic data are used for illustration purposes and are assumed to apply to each month of the year.

Monthly erosion potential (P)#				
Day of Month	Peak Wind (u^+_{10}) mph	Peak Wind (u^+_{10}) m/s	u* m/s	P g/m^2
6	29	13.2	0.70	5.87
7	30	13.6	0.72	6.97
11	38	17.3	0.92	18.25
22	25	11.4	0.60	2.11
			Sum of P	33.20

#-Assumed to apply to 12 months of the year.

The monthly erosion potential is multiplied by 12 and then by the field size (under activity data) and then divided by 2,000 lb/ton and 454 g/lb to compute the annual emissions in tons per year, as follows:

Annual emissions = (Emission Factor x Field Size)/2,000

- Annual PM10 Emissions = 2.19 tons/yr
- Annual PM2.5 Emissions = 0.88 tons/yr

Step 4. Calculate Controlled PM Emissions. The controlled emissions are calculated by repeating the entire calculation sequence but with a new assumed threshold friction velocity of 0.7 m/sec for a gravel surface.

Annual Controlled PM10 emissions = 0.13 tons/yr
Annual Controlled PM2.5 emissions = 0.05 tons/yr

Step 5. Determine Annual Cost to Control PM Emissions.

Capital costs ($)	4,000
Operating/Maintenance costs ($)	8,000
Overhead costs ($)	4,000
Enforcement/Compliance costs ($)	300
Annual Interest Rate	3%
Capital Recovery Factor	0.22
Total Cost ($)	16,300
Annualized Cost ($/yr)	13,173

The Capital costs, the Operating/Maintenance costs, and the Enforcement/Compliance costs are default values determined from current sources (e.g., Sierra Research, 2003[15]).

The Overhead costs are typically one-half of the Operating/Maintenance costs. Overhead costs = $8,000/2 = $4,000.

The Annual Interest Rate (AIR) is based on the most up to date information and sources.

The Capital Recovery Factor (CRF) is figured by multiplying AIR by 1 plus AIR, raised to the exponent of the Economic life of the control system, and then dividing by 1 plus AIR to the Economic life minus 1, as follows:

$$\text{Capital Recovery Factor} = \text{AIR} \times (1+\text{AIR})^{\text{Economic life}} / (1+\text{AIR})^{\text{Economic life}} - 1$$

$$\text{Capital Recovery Factor} = 3\% \times (1+ 3\%)^5 / (1+ 3\%)^5 - 1 = 0.22$$

The Total Cost is the sum of the Capital costs, Operating/Maintenance costs, Overhead costs, and the Enforcement/Compliance costs:

Total Cost = Capital costs + Operating/Maintenance costs + Overhead + Enforcement/Compliance costs

Total Cost = 6,000 + 8,000 + 4.000 + 300 = $16,300

The Annualized Cost is calculated by adding the product of the Capital Recovery Factor and the Capital costs to the Operating/Maintenance costs and the Overhead costs and the Enforcement/Compliance costs:

Annualized Cost = (CRF x Capital costs) + Operating/Maintenance + Overhead costs + Enforcement/Compliance costs

Annualized Cost = (0.22 x 4,000) + 8,000 + 4,000 + 500 = $13,173

Step 6. Calculate Cost-effectiveness. Cost-effectiveness is calculated by dividing the annualized cost by the emissions reduction. The emissions reduction is determined by subtracting the controlled emissions from the uncontrolled emissions:

Cost-effectiveness = Annualized Cost/ (Uncontrolled emissions – Controlled emissions)

Cost-effectiveness for PM10 emissions = $13,173/(2.19 - 0.13) = $6,400/ton
Cost-effectiveness for PM2.5 emissions = $13,173/(0.88 - 0.05) = $15,900/ton

8.8 References

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